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LF SEISMOGENIC EMISSIONS AND ITS APPLICATION ON THE EARTHQUAKE PREDICTION

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ABSTRACT

The authors are building a multi-point network system for the prediction of earthquake epicenter location by means of the seismogenic emission phenomena around Tokyo area. The network system consists of eight observation points with 50 km from each other and at each point a new digital type direction finding detector is set up with two loop sensors tuned to 82 kHz. The output signals of the receivers are added into the digital vector composition circuit to obtain the direction angle of the source point, and this signal is transmitted to the center computer through a telemeter line.

In order to protect from local man-made noise interferences, the warning is only anounced when the computation results of the center computer pointed one small area with high cross-corelation values for area from between all points. The source mechanism of emission related to precursors of earthquakes can be explained as electromagnetic emissions for the rocks around the focus when they are crushed completely by the distortion pressure. And these emission energies are propagated in the ground along the boundary surface of the fault as a surface wave mode and radiated from the slit antenna which consists of the boundary at the ground surface of the fault. The authors will present the computer flow and try to explain the source mechanism of these emission in this paper. Key - EARTHQUAKE, EMISSION from UNDER GROUND

INTRODUCTION

In 1980, the Japanese and Soviet cooperation project for the study of electromagnetic emission phenomena related to earthquakes has been started. And the first emission had been observed at 16:33JST(UT+9 hours) on March 31 in 1980, at Sugadaira Space Radio Observatory, University of Electro-Communications, Sugadaira, Nagano prefecture in Japan. The magnitude of this earthquake was about 7, and the depth of focus was approximately 480 km. The epicenter was located in the Kyoto prefecture and the distance between the Sugadaira observatory and the epicenter was approximately 250 km. The noise level recorder for 81 kHz recorded an anomalous high back ground noise level intensity. These levels were exceeded more than 15 dB over the usual level from 50 minutes before the main shock. The noise level intensity dropped sharply back to the previous level exactly at the moment of the shock. The noise level data of the VLF whistler recorder at Sugadaira Observatory observed that unusual impulsive emissions at frequencies below 1.5 kHz also occured before the earthquake. Similar 81 - 82 kHz emissions were observed prior to other earthquake of magnitudes between 5.5 - 6.5 on September 25, 1980, and on January 28, 1981. The location of these earthquakes were in the suburbs of the Tokyo area (Gokhberg et al., 1982).

Since 1981, the authors have observed several events of emissions just prior to earthquakes in the 81 - 82 kHz range. Based on these measurements, the authors started to set up a new multi-point observation network with direction finding capabilities around the Tokyo area. The purpose of this network is to investigate the possibility of locating the epicenter just prior to the earthquake and to eliminate the man-made noise interference for the improvement of the prediction accuracy. One of the most successful results of epicenter allocation by means of this network system was in the case of a typically "under foot" type of earthquake which occured around the southwest of Ibaragi prefecture at 21:14 JST on 27 February 1982. The magnitude of this earthquake was 6.3 and the depth of focus was approximately 40 km. The prediction result of direction finding of the epicenter location had been obtained successfuly by the following three observation points; Suginami in Tokyo, Sugito in Saitama prefecture, and Yatsugatak in Nagano prefecture. The forecast epicenter location of this earthquake had been located in the same area identificated by the predirection finding from above mentioned three observation points (Yoshino et al., 1985).

Since 1984, the authors set up a multipoint direction finding network with eight observationl points around the Tokyo region. The locations of observation points is as shown in Figure 1. And now we are building the data telemetry system for realtime computation of the cross-corelations during each other.(Yoshino et al., 1986a) and (Yoshino 1986b)

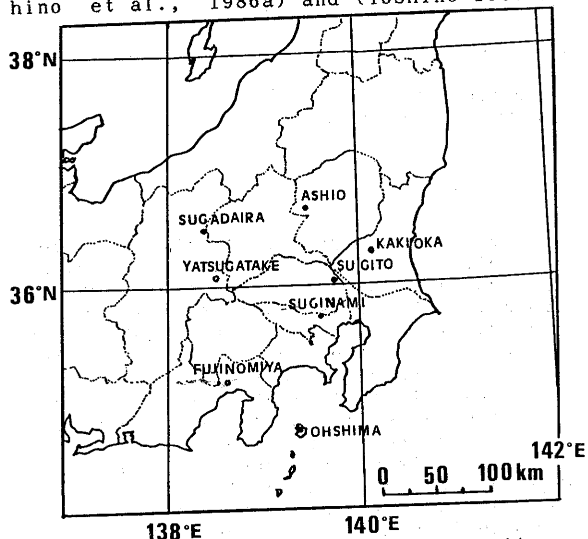


Figure 1, The location of observation points around the Kanto area of Janualy 1988.

On the other hand, the study on the radiation mechanism of electromagnetic emissions related the earthquakes as one of the precursor phenomena has been continued by Japan and U.S.S.R. since 1981. But these studies have been not not obtained a clear and reasonable result until today. Gokhberg and his colleagues of the U.S.S.R. had tried two different kinds of estimations, In the first, they try to estimate that this source existed in the bottom region of the ionosphere which preci-pitated the plasma instabilities by a large gradient of electric field at altitude of the ground surface, dE/dh, and the geomagnetic field intensity at the epicenter region (Gokhberg et.al. 1984). In the second, they changed this explanation to the electromagnetic emission which is produced by the micro-dislocation movement of the rocks before earthquakes in the shallow regions of the earth surface (Gokhberg et.al.1987). The observation systems and the research approach of the U.S.S.R. groups shifted toward lower frequency regions at the order of few Hz which were observed the electric field variations at the inner and upper ionospheric altitude regions by satellite observations since 1985 (Migulin et.al.1987) (Larkina et.al. 1987), and (Chmyrev et.al.). The authors have great trust in their results of these estimations, but the results are not sufficient explain of the phenomena of the source mechanism of emissions, the process of the electromagnetic energy transmission mechanism in the soils and rocks from the focus to the earth surface and the radiation mechanism of electromagnetic wave radiation at the surface of the ground.

Accordance to the laboratory experiments of our colleagues, their observational results show that the rocks emitted electromagnetic emissions when they crashed completely (Mizutani et.al. 1987). These similar type emissions from

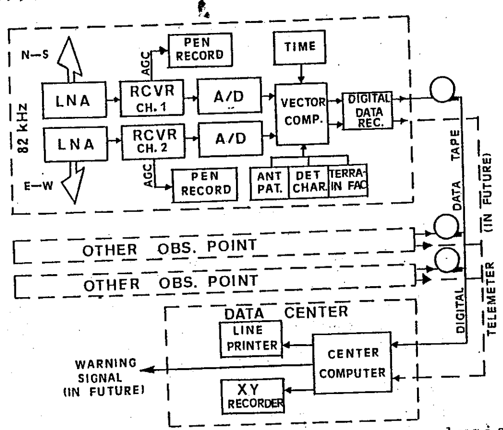


Figure 2 A block diagram of data analysis system for electrogenic earthquake precursor observation.

rocks were observed at the volcano eruption of Mt. Mihara on November 21st in 1986 (Yoshino et.al.1987). During the entire duration of the eruption, the emissions were only observed when the dyke of magma inserted into the mountain body caused the crushing of rocks.

In order to explain the transmission process of the energy of emitted electromagnetic impulses from the source around the focus area to the surface of the ground, the authors have applied a surface mode transmission uradel. The conductivities of inside the fault have usually very high values compored to the values of outside, and the conductivity gradient is distributed along the direction of fault lines. Such characteristics of surface condi-tions of faults will be able to support the surface mode propagation along this boundary from the focus point to the ground surface. One of the estimation results for optimum condition is 25 dB below the case of usual plane wave propagation in the homogenous soils and rocks at the same distance. In order to explain the radiation condition at ground surface, the impedance matching at the terminated point of the ground surface between the surface to free space propagation mode obtained below 1.5 of VSWR according to calculation results by using the optimum case when the boundary of the fault line consist of a slot dipole antenna at ground surface.

Based on the above mentioned results,

the authors try to attempt the explanation of the source mechanisms for the electro-magnetic precursor emission phenomena in this paper.

EQUIPMENT FOR DETECTION OF SEISMOGENIC EMISSION

Figure 2 illustrates a block diagram of a standard detection unit of the multipoint network system and a flow of the data processing for the prediction of epicenter bearings by means of electromagnetic precursor emission in each observation point. As shown in this figure, a sensor consists of a frequency tuned loop antenna and two loop antennas are set up perpendicular to one another towards north - south and east - west each for the direction finding purpools. Each loop antenna consist of 50 turn coil wounded on a 85 cm diameter with electrostatic shielding and tuned to 82kHz. The output signal at the terminal of a tuned loop antenna is connected directly to a low-noise preamplifier with a gain is approximately 23dB, and this circuit boards are mounted in a small water proofed antenna center box.

The circuit structure of the main receiver unit consists of two receivers, each receiver unit consists of basically a single super-heterodyne receiver for 82 kHz. A single stage RF amplifier has four stages of multiple tuning coils to compensate to the band-pass characteristics. And two stage of IF amplifiers are tuned to 455 kHz connected after a convertor circuit with crystal controlled local oscillator. The sensitivity of the main receiver is as shown in Figure 3, and the overall band-pass characteristics are shown in Figure 4,

The output signal of an analog envelope detector from these two receivers is transfered automatically as the digital signal level into an installed micro-computer system through a 16 bit analog-to-digital convertor circuit, and both digital signal levels of north - south and east - west directions are added into a digital vector composition circuit to obtain a direction angle and the levels of incoming signal. AT this stage, the values of both output signal levels from both receivers are compensated automatically with the direction pattern characteristics of each antenna, the detection characteristics of each receiver, and the other local terrain factors at each observation environment to keep a high accuracy of the prediction level.

After the above mentioned computation for each observation point, the computer calculation results of composit vector directions are transmitted to the center computer of the earthquake prediction and warning center through the telemeter system of telephone cables, microwave links and optical fibre cables, and these data are also stored in the digital recording tape at each observation point. Now our testing network around the Tokyo area is built up at eight points separated by intervals between each other of approximately 50 km mesh.

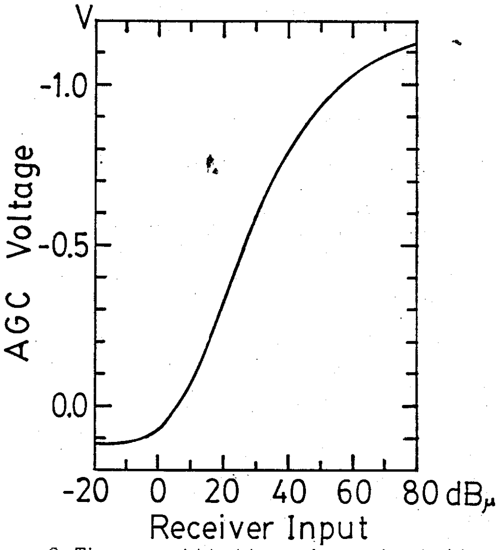


Figure 3 The sensitivity characteristics of the main receiver for 81 - 82kHz observations.

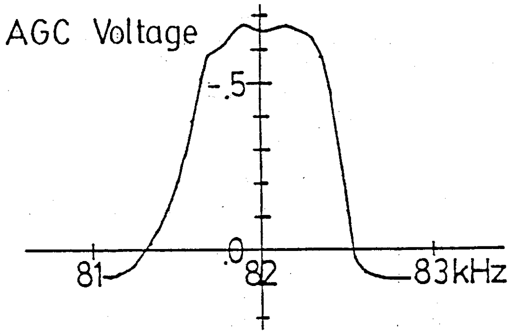


Figure 4 The band pass characteristics of the main receiver for 81 - 82kHz observations.

PROTECTION FROM MAN-MADE NOISE INTERFERENCE

The bearing data which are observed by all observation points are transmitted to the local earthquake prediction and warning center through telemeter lines, and are computed further in order to obtain the bearing and location of the noise emission source. To protect from misalarm for earthquake prediction warning, we only announce when all of the computational results of emission bearings are pointed to a small single area with high level of cross-corelations of the bearing data between all or several numbers of observation points around the strict area.

In order to eliminate the man-made noise interference, if a strong noise signal has been received at one observation point, but the computational results of the cross-corelation between all other stations are not pointed at a single point with no corelation obtained at the center computer, the alarm signal is not announced as for example in the case of man-made noise interference, because the usual man-made noise are not radiated beyond 50km from their sources.

THE PROBLEMS OF OBSERVATION FREQUENCY

The reason why the authors selected 81 - 82 kHZ as the obser-vation frequency of seismogenic emissions during the first mesurement in 1980, this frequency range was only found as a frequency window which protected sufficientes from man-made noise sources based upon the results of very careful searching through the frequency spectrum for several months. This because so many radio transmitters and other man-made noise sources are widely spread across the frequency range from ELF to EHF in the Japanese island. But the natural background noise level during night time at these frequencies of 81-82 kHz is usually 6 to 10 dB higher than at daytime due to the noise signals generated by lightning discharges of the thunder-storms in the tropical region. And the threshold level of background man-made noise in this frequency range is also increasing in the last decade. So the authors tried the search for new observation frequency ranges for the

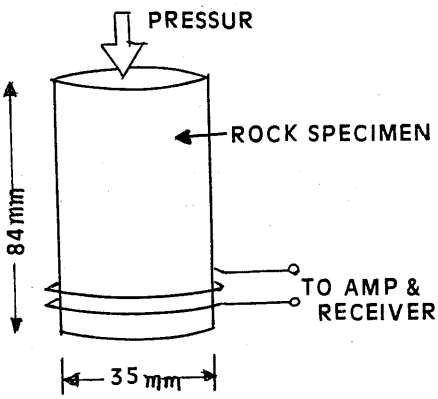


Figure 5 The size of rock specimen for electromagnetic emission observation, before they are crushed by pressure machines. (after Mizutani 1987)

reduction of background noise interference at 82 kHz. And now we are selecting the following two frequencies of 1.6 kHz and 36 Hz. The main reason of the high back ground noise level during night time is the lightning shot noise propagated from tropical regions. The ionospheric propagation mode of VLF waves are usually transmitted by the guided mode propagations, and this guided mode propagation has a lower cutoff frequency with respected to the dominant frequency. The usual cutoff frequency of dominant modes of the night time ionosphere is approximately 1.8 kHz. Then 1.6 kHz waves will not be able to propagate the noise of lightning discharge of far the distant tropical region to middle latitude regions. On the other hand, the frequency range between approximately 7 Hz to 45 Hz is globally spreaded very noisy frequency range due to the Schumann resonance phenomena. But the noise level spectrum in the Schumann resonance band has the characteristics similar to a gaussian distribution, thus the back ground noise level of 36Hz will be reduced as nealy neglegible. The frequency range below 5Hz is disturbed by the strong continuous pulsations (PC-1) and (PI-1) emission, and it will be very difficult to clearly select natural noise emission or geomagnetic field pulsation phenomena, when observations are made on this frequency range.

MODEL OF RADIATION MECHANISM OF SEISMOGENIC EMISSIONS

As the authors have offered as a poinble cause of the radiation mechanism of the seismogenic electromagnetic radiation in the introduction of this paper, the emission will be induced as one of the kinds of boundary charge phenomena when the rocks around the focus of earthquakes will be forced to crush under the very strong distor-tion forces increasing rapidly at just prior to earthquakes. The laboratory experiments have been done by Mizutani (Mizutani et.al.1987) since 1981. In these experiments, very strong electromagnetic impulses were observed at the same instanteneous time when the spacimen of rocks has crushed by the high pressure crush test

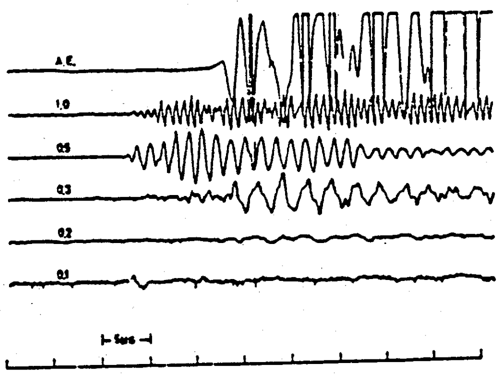


Figure 6 Acoustic emission (top) and EM emission wave form observed at 1.0, 0.5, 0.3, 0.2 and 0.1 MHz.(from second top to the bottom) The time difference between the AE and EM onset times correspond to the traveling time of AE. (after Mizutani 1987).

machine. The values of induced electromagnetic emission obtained were different for each kind of rock, wet or dry, and are dependent on the many different conditions at the time of observations. The size of spacimen is as shown in Figure 5 and one of the examples of experimental curves is shown in Figure 6.

The authors have built a model to explain the radiation mechanisms of seismogenic emission as shown in Figure 7. Usually the focus area of earthquakes is located inside of and beside the fault as shown in this figure. If the distortion forces are increased in the fault area, the crush of pieces of rocks is initiated and the energy of induced electromagnetic impulses are emitted within this region in the fault.

The electric conductivities inside and directed to wand the fault line is usually higher than for outside rocks, and the conductivity difference between inside and outside of the fault is approximately over 20 dB. Also a sheath structure of high dielectric soils is often observed on the boundary surface of fault. This surface condition of boundary will be able to support the surface mode of the TEM-electromagnetic wave propagation along the boundary of the fault, and the energy of seismogenic emission will be able to transmit from the source of depth to the earth's surface with very lower attenuation as compared to the usual plane wave propagation outside of the boundary.

The surface mode propagation of electromagnetic waves was developed by Goubou(Goubou 1950,Cullen 1954) and today this advanced technique is often applied on modern micro wave circuit designs of the micro-print-board for compact equipment system of the centimeter and millimeter wave bands. The profile of surface boundary structure illustrated in the Figure 8. AS shown in this figure, the boundary structure of a fault has a structure similar to a surface wave transmission line.

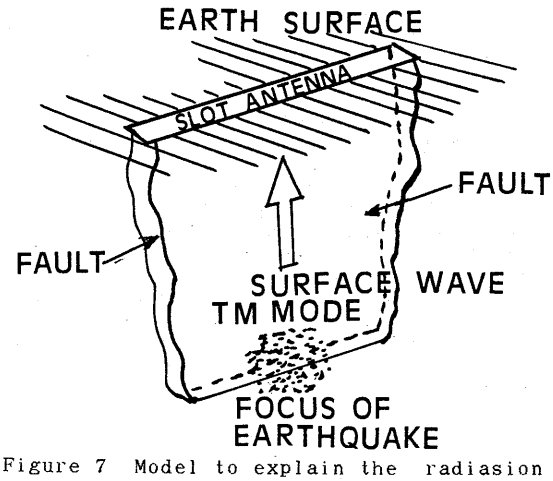


Figure 7 Model to explain the radiasion mechanism of seismogenic emission.

The results of the numerical simulation on the estimation of attenuation values for the surface mode wave propagation along the boundary surface of the fault are as follows:

(1) resistivity of outside of fault is 10 kohm/meter,
(2) resistivity of inside to and parallel to the direction of the fault is less than 10 ohm/meter,
(3) specific dielectric constant at boundary surface of fault is 20, and at outside area of fault is 6.0.
(4) frequency is 82 kHz and 1.6 kHz,
(5) depth of focus is 50 km.
(6) TM mode.

The calculated value of total propagation loss for 82 kHz is approximately 63 dB, for the case of dielectric sheath thickness at 10 meter, and 65 dB for 20 meter. And in the case of 1.6 kHz is approximately 56 dB in power ratio. If a high amount of aciduous water is filled in the fault, the values of propagation loss will decline more than 10 dB from above calculated values.

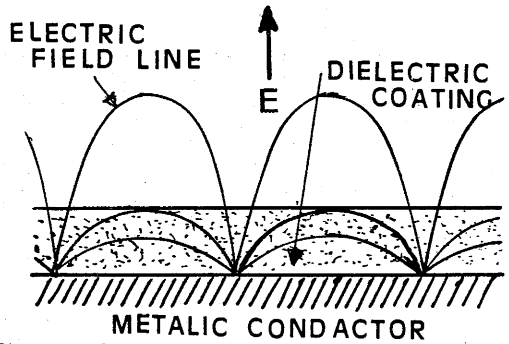
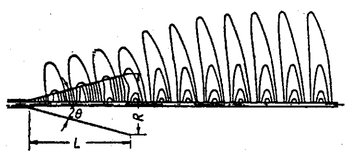


Figure 8 The structure of the surface wave transmission line and he electric field lines of forces distribution of the dominant TM mode.



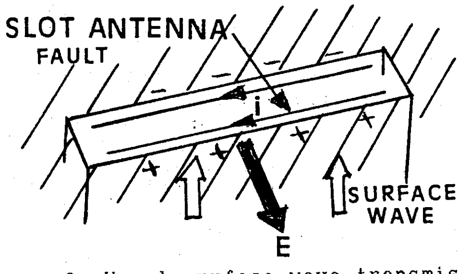


Figure 9 Usual surface wave transmissiom line terminated with horne excited from TEM mode coax. line to TM mode surface mode line.

The calculated attenation value of plane wave propagation outside of the fault area for 82 kHz is approximately 85 to 88dB, and for 1.6kHz is approximately

80 dB, if the media is spread by homogeneous soil and rocks. From these simulation results, the value of transmission loss for surface mode propagation is about 25 dB below the value of plane wave propagation in the same depth.

The radiation impedance matching between surface mode feed and free space radiation mode by a slot antenna which consists of the boundary between the top end of the fault and the ground surface was also simulated for many types of the matching system, and one of the best cases of VSWR values can be obtained as 1.5 for the structure shown in Figure 9. The authors are continuing the estimation and the experiment on surface mode propagation and impedance matching for surface radiation by means of the scale model of higher frequencies.

CONCLUSION

As shown in this paper, the building of a multipoint network observation system for the prediction of earthquakes and its epicenter location by use of the seismogenic electromagnetic emission phenomena is progressing positively with research group of the authors. The characteristics of the receiving system and the practical design on the details of facilities are completed already, and now we are continuing the telemetry system development for high speed,high accuracy, the highest reliability and the lowest operation cost for non-stop and long-term automated operation. We are developing the computer software system to obtain the most reliable detection algorithm transmission for the predetection of earthquakes and their epicenter location which calculated with the center computer at the local earthquake alarm center.

The most impotant aspect for the developement of above mentioned automaic alarm system for earthquakes by using the detection data of seismogenic electromagnetic emission is the protection and discrimination against of the man-made noise interference. The authors are developing a man-made noise reduction method by means of the multipoint network system which is spread over eight observation points and the distance between point to point is approximately 55 km. Each observation point consists of a LF (82 kHz) direction finding system, and the observation results of direction bearing and signal intensities are converted to 16 bit digital values and transfered through a telemeter system to the center computer in the warning center. When the center computer evaluating these data and if the values of cross corelation appear to be high values and the bearing data of all or several points and directed to one area, the alarm signal will transmit a pre-warning of earthquakes and show the predicted epicenter area automatically. When the strong signal intensity is observed at only one or few points, but the calculation values of cross corelation are still very low; then this increase of signal intensity can be omitted as man-made noise interference by the center computer. Although the authors had only one case of success to predict the epicenter location and prediction before an earthquake (Yoshino et.al. 1982), we have stored several other observational data. The authors believe strongly this system will be one of the most reliable systems for the method of man-made noise reduction. And we have started the search of new observation frequency ranges in the VLF range, below the cut-off frequency of the VLF ionospheric guided mode propagation (1.6 kHz) and the higher frequencies of ELF (36 Hz) in the Schumann resonance band. The trial to elimlnate natural noise interference of lightning discharges in the tropical regions were started by our research groups .

In the investigations about the noise source and propagation path of seismogenic electromagnetic emissions as the precursor of earthquakes, the authors utilized the experimental results of the electromagnetic emissions due to the crushing of rock by Mizutani (Mizutani et.al.1987) to explain the mechanism of emission around the focus area of the earthquakes. And we also applied the theory of surface mode propagation of electromagnetic waves along the boundary surface of a fault to explain why the energy transmission of seismogenic emission from the focus to the ground surface is smaller attenuations in comparison with the case of usual plane wave transmission. On the problem of the radiation mechanism of waves at the surface of the ground, the authors applied the radiation mechanism of slit antennas which consists of the top of the fault at ground surface. But the theoretical explanation about the impedance matching between surface mode transmission line to slit antenna is very compli-cate and now still requires a more detailed investigation.

As a reasonable result of roughly estimating the transmission loss by use of an optimum value on the assumption that the averaging of measurement values for a usual fault spread in the Kanto area, the authors conclude that the total attenuation loss for a specific case of the surface mode transmission and slit antenna radiation was 26 dB lower than the case of usual plane wave transmission without fault. The precise investigations for this problem have to be contnued for the each case of earthquake observed from now.

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